LA-UR-19-20636
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Title: Shock Initiation Measurements of PBX 9404; Lot 10102Y, FY2018

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Intended for: Report

Issued: 2019-01-28

Shock Initiation Measurements of PBX 9404; Lot 10102Y, FY2018

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(Dated: 17 January 2019)

I. EXPERIMENTAL SETUP

This report details a series of 5 shock initiation experiments on PBX 9404, Lot 10102Y. These experiments cover a pressure range of 2.98–6.66 GPa, and were conducted at the LANL TA-40 Chamber 9 gun facility. 4 experiments (shot numbers 1s-1665–1668) were performed using the single-stage gas gun, and the fifth on the two-stage gun (shot number 2s-1079). A pair of cylindrical PBX 9404 30 degree wedges were assembled into a right cylinder (nominally 43 mm⌀ and 23 mm tall) with an embedded electromagnetic velocity (EMV) gauge package glued between them. A 'stirrup' EMV gauge was also glued to the impact face of the target. The gauges consist of Al conductors sandwiched between FEP Teflon, and produce a voltage proportional to local particle velocity as they move through a static magnetic field. Gauges are nominally spaced 0.8 mm apart for the first 7.5 mm of the depth of the target. Precise gauge depths for each experiment are given in their respective small scale database entries. All glue bonds were made with Dow Corning 733 Silicone. The configuration of this experiment is shown in Fig. 1. A summary of experimental conditions explored is given in Table I.

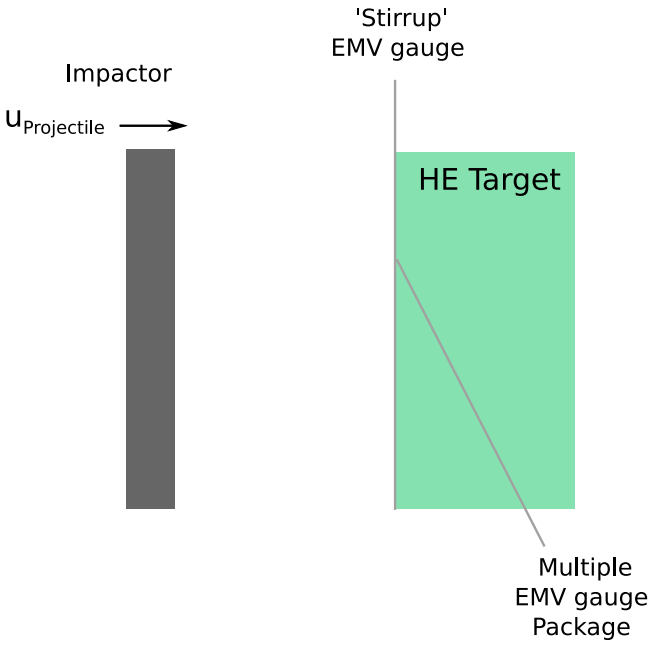

FIG. 1. Schematic of the experimental setup. An embedded gauge is glued between a pair of PBX 9404 wedges and impacted by a sapphire or Kel-F81 impactor.

A. Projectiles and Impactors

All single stage experiments used a short Mg spool projectile with a 100 mm Lexan outrigger and a 10 mm thick sapphire impactor. The two stage experiment used a standard Lexan two-stage projectile with a 6 mm thick Kel-F81 impactor. Impact velocity in each experiment is tabulated below (Table I).

II. RESULTS

Table I lists summary data for all the PBX 9404 experiments in this series. Impact conditions are calculated by impedance matching. The equations of state used for the Kel-F81 and Sapphire were obtained from a fit of Sheffield and Marsh data, and a reference by Barker, respectively.[1–3] The PBX 9404 Hugoniot used was obtained in this work, and is reported in Table II.

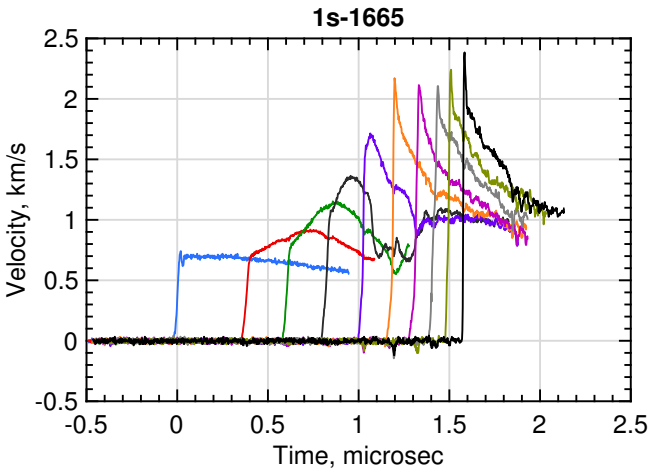

FIG. 2. Wave profiles from embedded particle velocity gauges for shot 1s-1665.

A. Wave Profiles

Figure 2 shows wave profiles from the embedded electromagnetic particle velocity gauges for shot 1s-1665. Onset of detonation in this shot occurs between gauges 5 and 6. Wave profiles and gauge locations for all shots in this series are available on the small scale database.

TABLE I. Summary of this series of shock initiation experiments. Run to detonation were calculated using the x-t data from each experiment and the method of Hill and Gustavsen[4].

Shot #	Rho0 g/cc	Impactor	Impactor Velocity km/s	Pressure Gpa	x_D mm
1s-1668	1.840 ±0.001	Sapphire	0.517 ±0.001	2.98 ±0.05	11.2 ±0.2
1s-1667	1.841 ±0.001	Sapphire	0.570 ±0.002	3.36 ±0.05	9.6 ±0.2
1s-1666	1.840 ±0.001	Sapphire	0.676 ±0.003	4.18 ±0.05	6.9 ±0.2
1s-1665	1.841 ±0.001	Sapphire	0.808 ±0.003	5.27 ±0.05	4.85 ±0.2
2s-1079	1.841 ±0.001	Kel-F81	1.703 ±0.001	6.66 ±0.05	3.14 ±0.2

TABLE II. $U_s - u_p$ Hugoniot fits used to calculate impact pressures in this work. Fits are of the form $U_s = su_p + C_0$

Material	ρ_0 g/cc	C_0 km/s	s	Ref.
Kel-F81	2.137	2.032	1.676	[1,2]
Sapphire	3.985	11.19	1.0	[3]
PBX 9404	1.841	2.55	2.30	This work

B. Calculation of Run Distance to Detonation, x_d

Data from both the embedded particle velocity gauges and shock tracker gauges are first combined to create an x-t plot, showing wave time of arrival vs position (Figure 3). These data are then fit using an acceleration function, following the methods of Hill and Gustavsen[4]. The onset of detonation in each shot is extracted and specified in Table I.

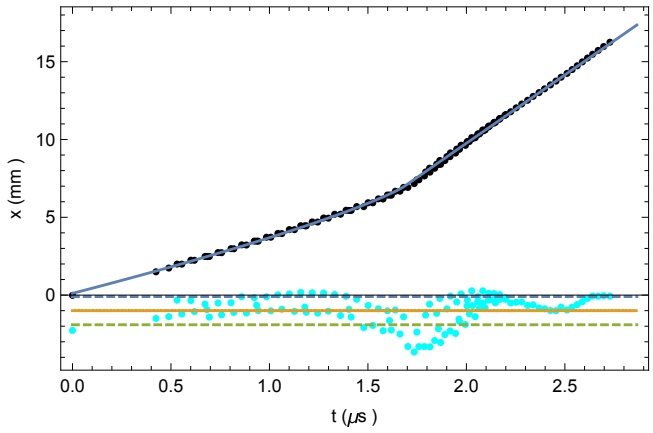

FIG. 3. $x(t)$ trajectories from gauges and shock trackers in shot 1s-1666 (black points). These data are fit using the method of Hill & Gustavesen[4], shown as a blue line. Cyan points are 10x residuals of the fit to each data point.

C. Unreacted Hugoniot

In this series a total of 31 unreacted Hugoniot points were determined, covering a range of P =2.7–17 GPa and u_p =0.408–1.51 km/s. These points were extracted using one of two methods. Hugoniot points at the impact face were determined by impedance match with the impactor material, using the measured u_p. This leads to large error bars in experiments using sapphire impactors due to their high stiffness. The second method uses the embedded gauge records prior to detonation. Particle velocity at the shock jump is extracted from each record using two

TABLE III. Hugoniot points extracted from the embedded gauge records.

Shot #	Rho g/cc	Us km/s	up km/s	Us err km/s	up err km/s
1s-1665	1.841	3.85	0.699	0.60	0.01
		4.05	0.696	0.15	0.01
		4.47	0.775	0.15	0.01
		4.91	1.016	0.15	0.01
		5.72	1.547	0.15	0.01
1s-1666	1.840	3.92	0.583	0.60	0.01
		3.69	0.559	0.15	0.01
		3.86	0.598	0.15	0.01
		3.96	0.626	0.15	0.01
		4.21	0.700	0.15	0.01
		4.60	0.861	0.15	0.01
		5.95	1.345	0.15	0.01
1s-1667	1.841	3.84	0.487	0.15	0.01
		3.88	0.507	0.15	0.01
		3.87	0.547	0.15	0.01
		4.04	0.594	0.15	0.01
		4.31	0.670	0.15	0.01
		4.84	0.825	0.10	0.01
1s-1668	1.840	3.16	0.458	0.60	0.01
		3.46	0.408	0.15	0.01
		3.69	0.435	0.15	0.01
		3.49	0.443	0.15	0.01
		3.54	0.450	0.15	0.01
		3.60	0.462	0.15	0.01
		3.65	0.489	0.15	0.01
		3.67	0.508	0.15	0.01
		3.90	0.556	0.15	0.01
2s-1079	1.841	4.43	0.817	0.15	0.01
		4.53	0.857	0.15	0.01
		4.89	1.093	0.15	0.01
		6.12	1.511	0.15	0.01

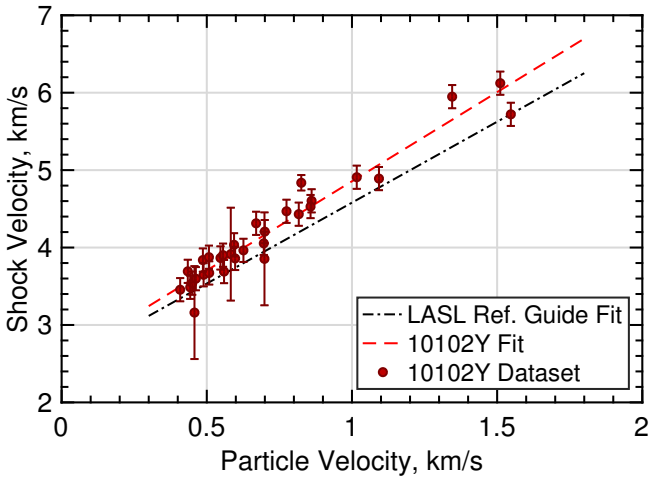

FIG. 4. Hugoniot points extracted from all embedded gauge shots in this series.

linear fits, one to the shock rise and one to the initial slope of the reactive hump. The crossing point of these fits is taken as the extracted u_p. Shock velocity at gauge n is determined by dividing the measured Δt between gauges $n-1$ and $n+1$ by the distance between them. Hugoniot points and estimated errors are reproduced in Table III, and shown in Figure 4.

The author is aware of only one previous Hugoniot fit, found in the LASL Explosive Property Data guide[5]; this fit is plotted against the present data (material lot 10102Y) and fit in Figure 4. The source of this Hugoniot is unreferenced, and the raw data could not be located. The Hugoniot fit determined in this work is of slightly higher impedance than the LASL fit. Without the source data used to make the LASL fit it is difficult to make a detailed comparison.

D. PBX 9404 Pop-plot

Figure 5 shows both data from this series (red points) and unpublished legacy data from B.G. Craig, which were digitally extracted from a figure by Forest[6] (blue points). Two linear fits are also presented; the dashed red line represents a fit to data exclusively from this series, and the black dashed line represents a fit to all data shown. Fit parameters for both these fits, and the unreferenced fit in the LASL Explosive Property Data guide[5] are given in Table IV. Pop plot points from lot 10102Y are slightly less sensitive than the LASL Pop plot fit and the Craig data. Although no error is specified with the Craig data, based on the observed scatter, the two data sets are likely within experimental error of each other.

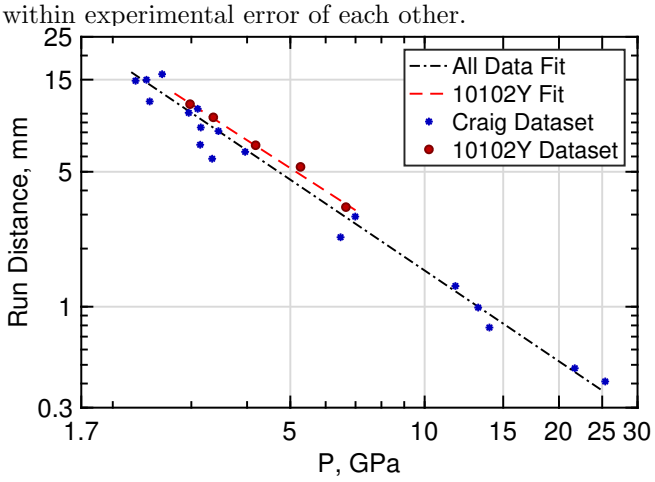

FIG. 5. Pop-plot for PBX 9404. Red points and dashed line are data and fit to lot 10102Y data of this work, with error bars on the order of the point sizes. Blue points are unpublished legacy data from B.G. Craig[6], with unknown error. The black dashed line represents a fit to both the lot 10102Y data and the Craig data.

TABLE IV. Pop plot fit parameters for PBX 9404. Fits are of the form $Log(P) = a + bLog(x_D)$

Fit Name	ρ_0 g/cc	a	b	Ref.
Lot 10102Y	1.841	1.18 ±0.08	-0.67 ±0.07	This work
Combined Fit	1.841	1.12 ±0.01	-0.64 ±0.01	This work,[6]
LASL Fit	1.84	1.11 ±0.01	-0.65 ±0.01	[5]

III. REFERENCES

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[5]T. Gibbs and A. Popolato, "Lasl explosive property data," *University of California Press*, 1980.
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